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Title: The Physics of Disorder

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The Physics of Disorder

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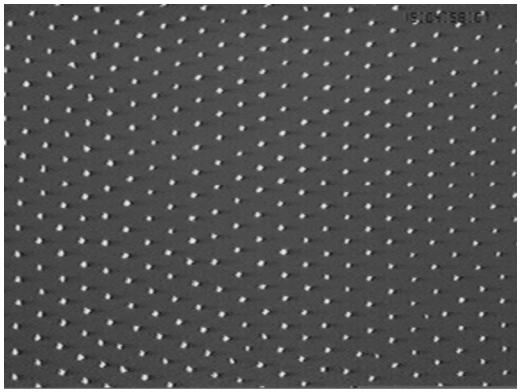
October 22, 2018

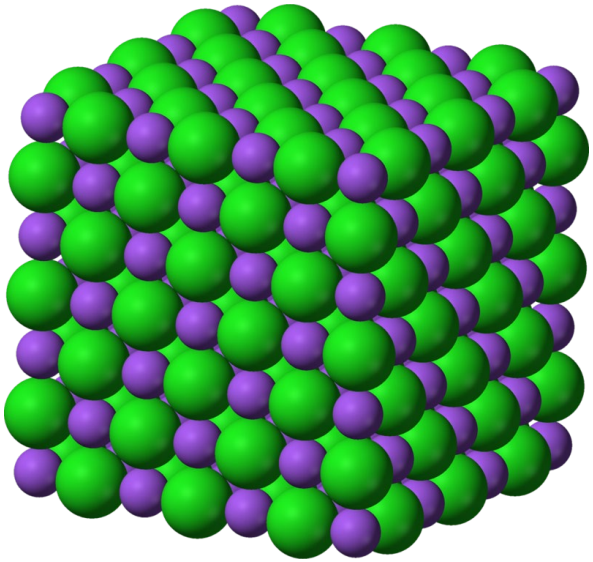
National Nuclear Security Administration
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

Order versus Disorder

- **We are good at characterizing ordered states**

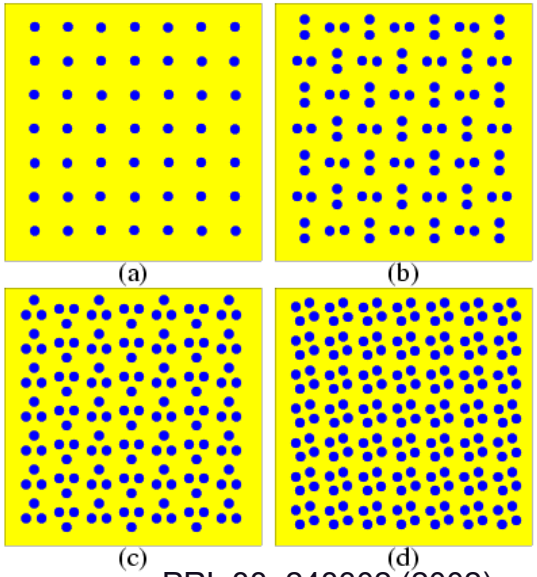
Triangular lattice

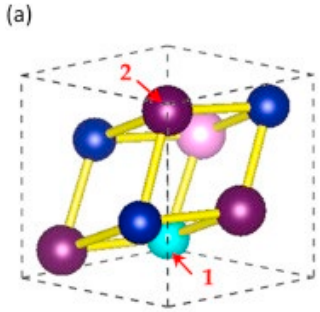


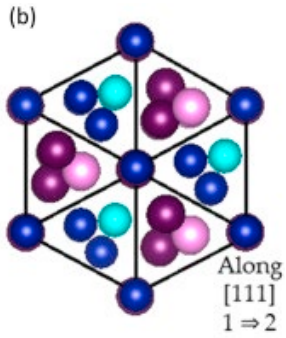


Face-centered cubic lattice

Square lattice







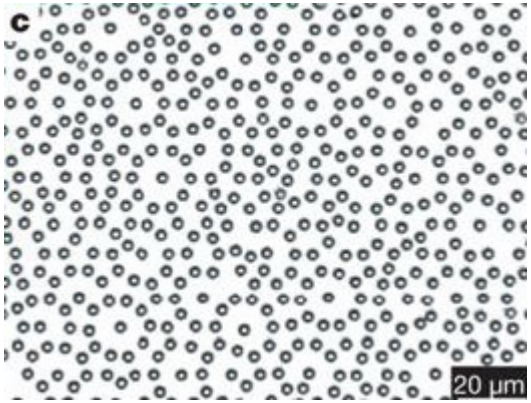
Chiral B20 lattice

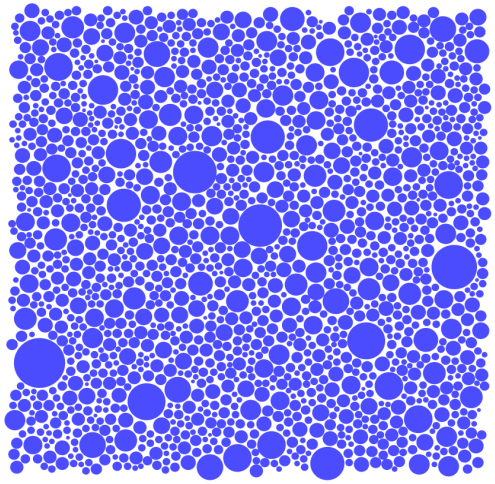
PRL 88, 248302 (2002)

Order versus Disorder

- **We are not good at characterizing disordered states**

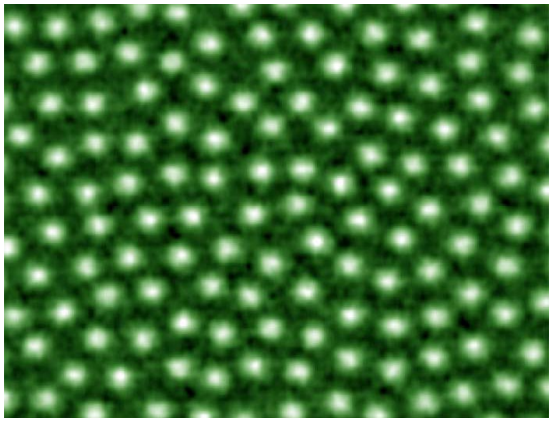
Disordered

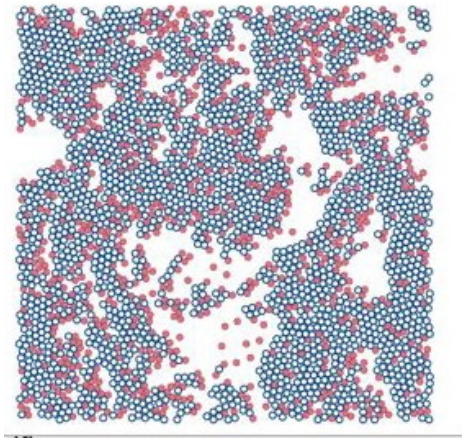




Disordered

Disordered



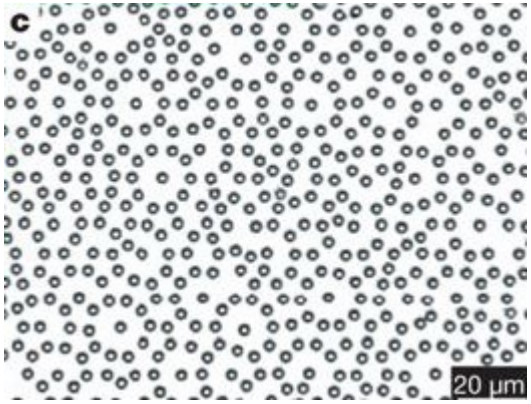


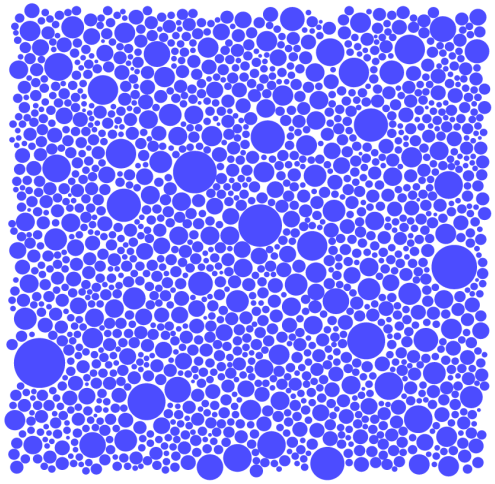
Disordered

Order versus Disorder

- **Development of a new language to classify disordered states**

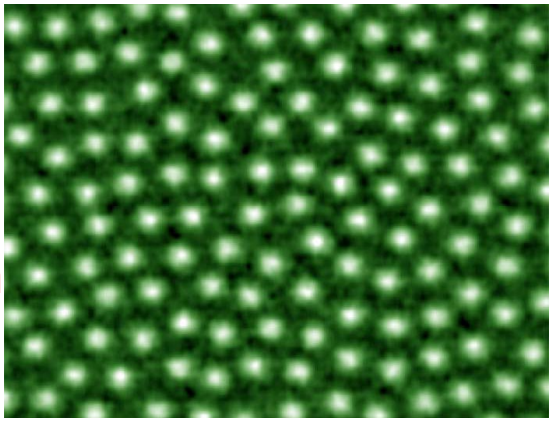
Disordered
Quasicrystal
(Shechtman, 2011)

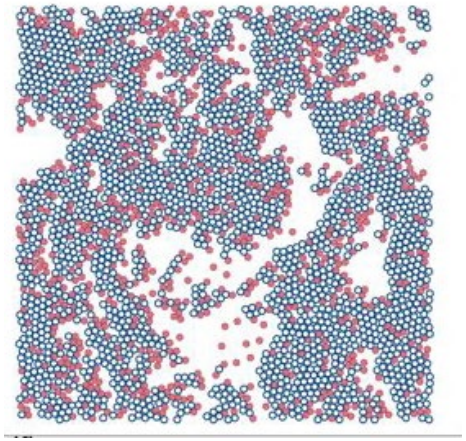




Disordered
Jammed

Disordered
Hyperuniform

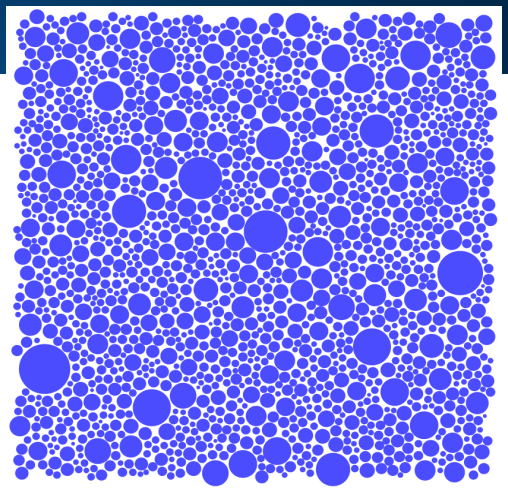


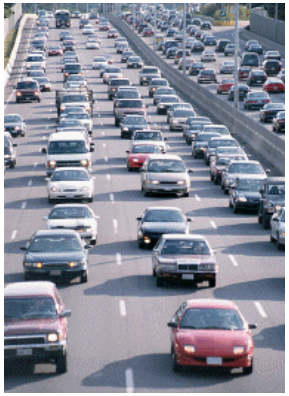


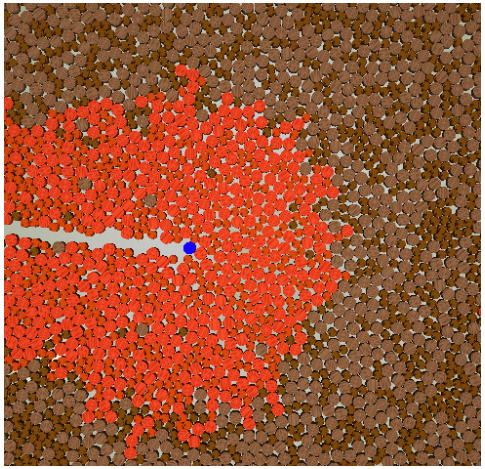
Disordered
Clogged

Jammed states

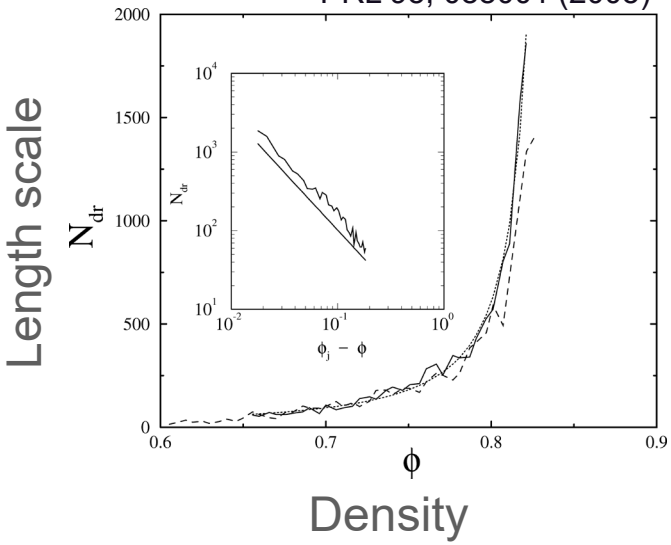
- Systems with no tensile strength form a solid through confinement
- Dynamics: increasing density causes transition from flowing to jammed
- No temperature, yet transition appears "thermal"







PRL 95, 088001 (2005)

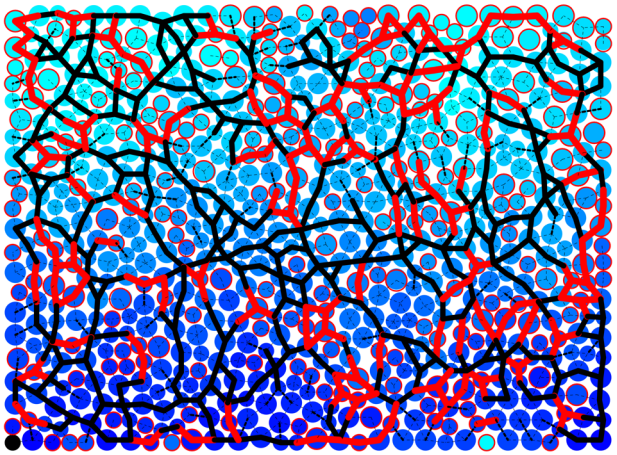


Power law divergence of length scale

$\xi \propto (\phi_c - \phi)^{-\nu}$

Examples of jammed-unjammed transitions

PRE 92, 022203 (2015)



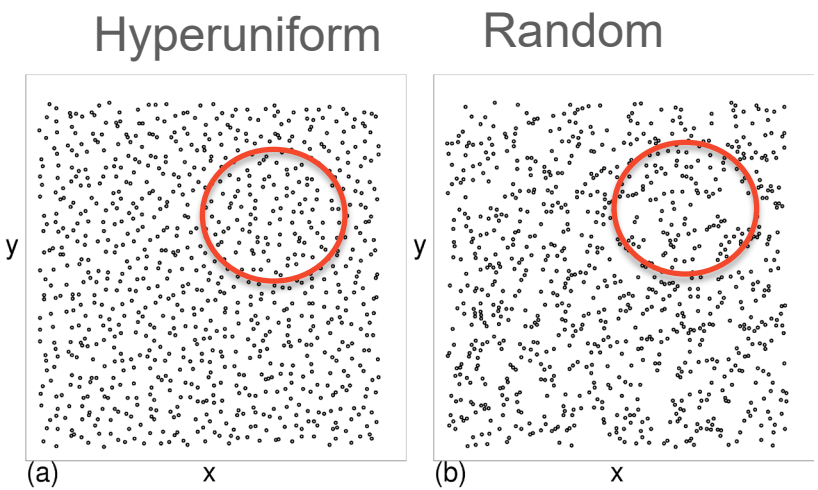
Force transmission in jammed state is very nonuniform

Hurricane Rita evacuation, 2005

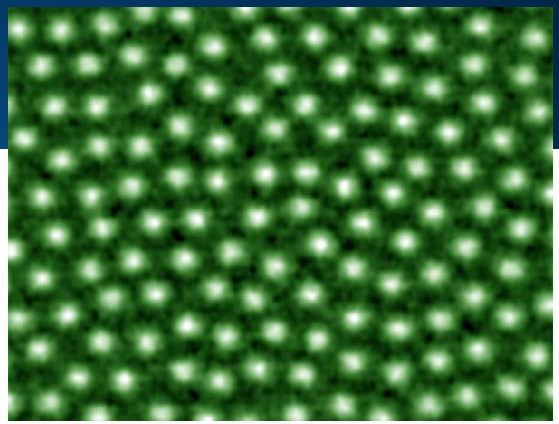
Grain silo collapse

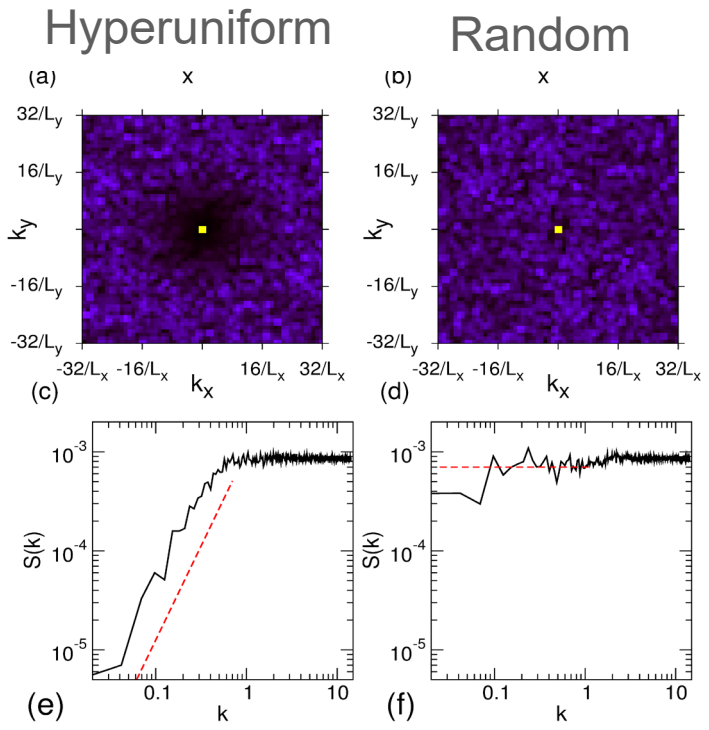
Haiti 7.0 earthquake, 2010

Hyperuniform states



PRB 96, 094516 (2017)





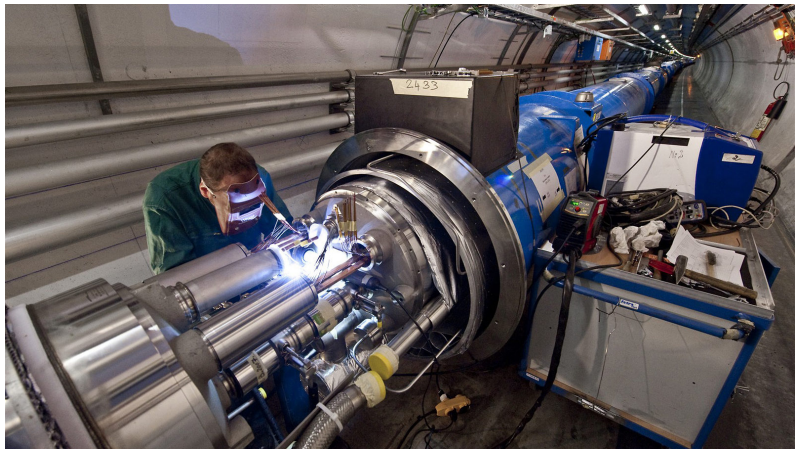
- **Density fluctuates on short scales but is uniform on large scales**
- **Structure factor goes to zero at small wavelengths as a power law**

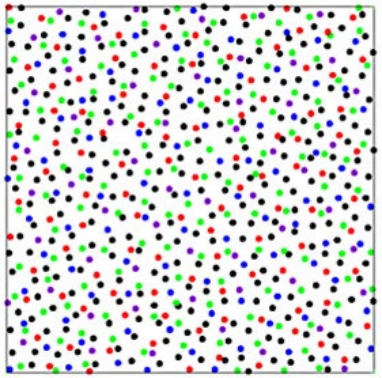
$S(\mathbf{k}) \sim |\mathbf{k}|^{\alpha}$ $S(\mathbf{k}) \sim$ constant

Uses for hyperuniformity

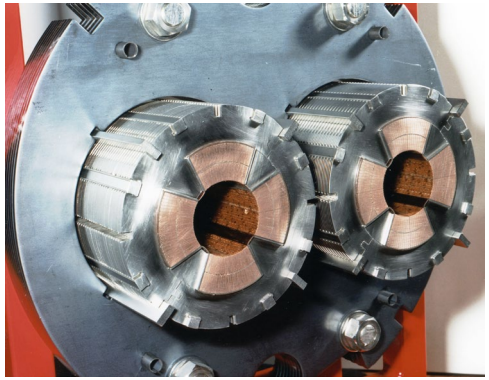
- **Magnetic vortices in type-II superconductors form a hyperuniform state**
  - Exploit this to increase critical current (maximum operating current) of superconductor and improve magnet performance and robustness
  - Future accelerator technology
- **Also found in chicken eye**

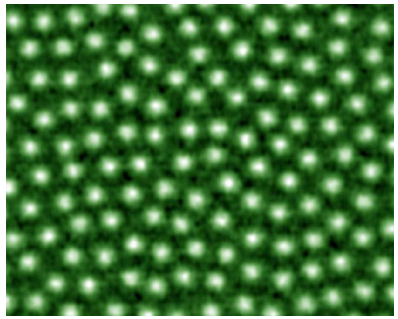
Superconducting magnets at the Large Hadron Collider





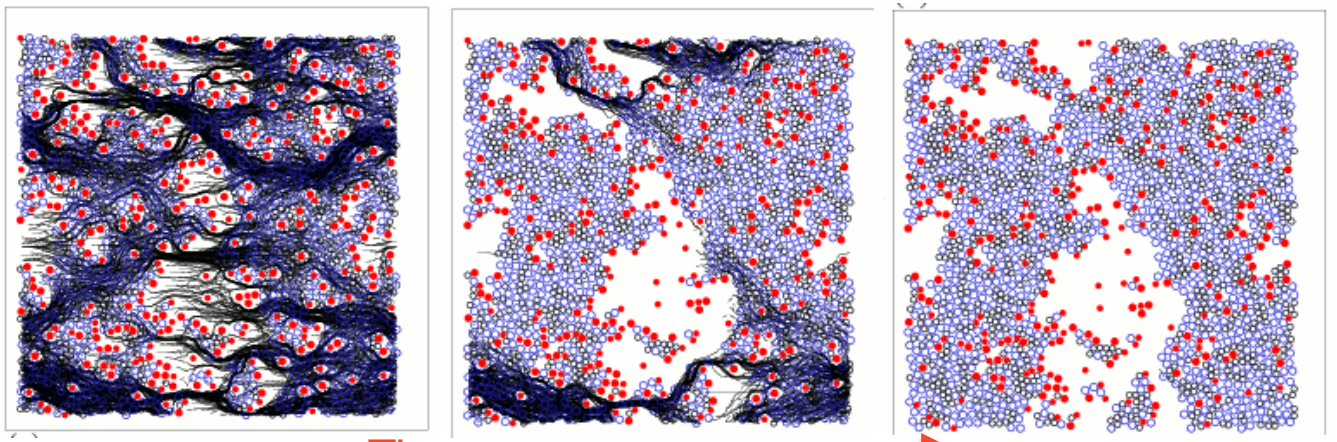
Jiao et al PRE 89, 022721 (2014)



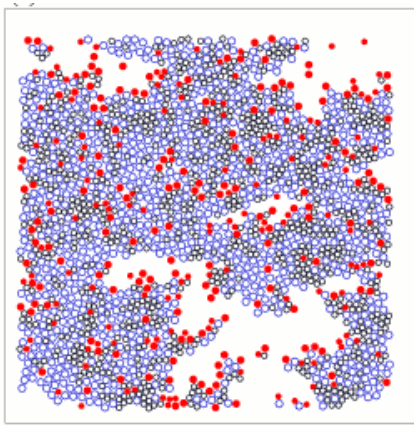


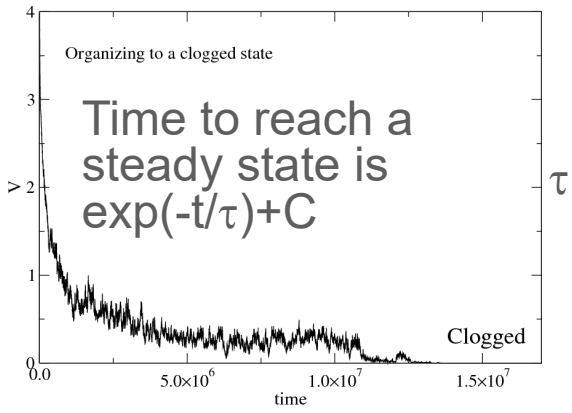
Clogged states

Disks sliding through obstacles



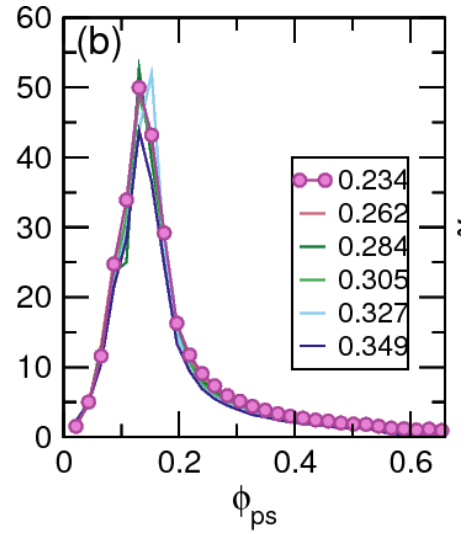
- **Spatially nonuniform**
- **Require long times to form**
- **Associated with memory**





τ diverges at a critical obstacle density

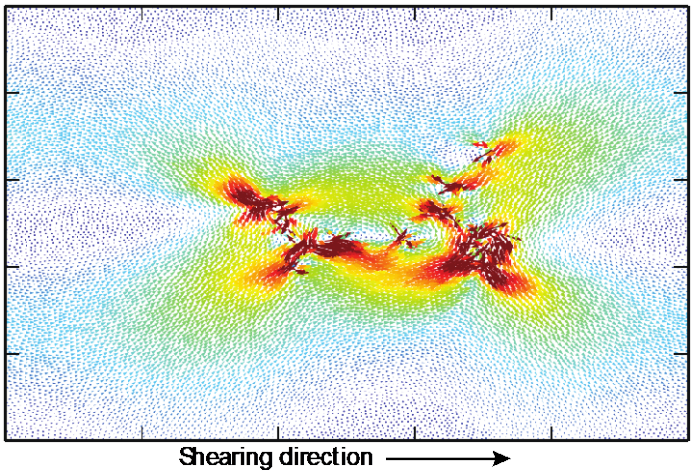
$$\tau \propto (\varphi_{obs} - \varphi_{cc})^{\gamma}$$



Sci. Rep. 8, 10252 (2018)

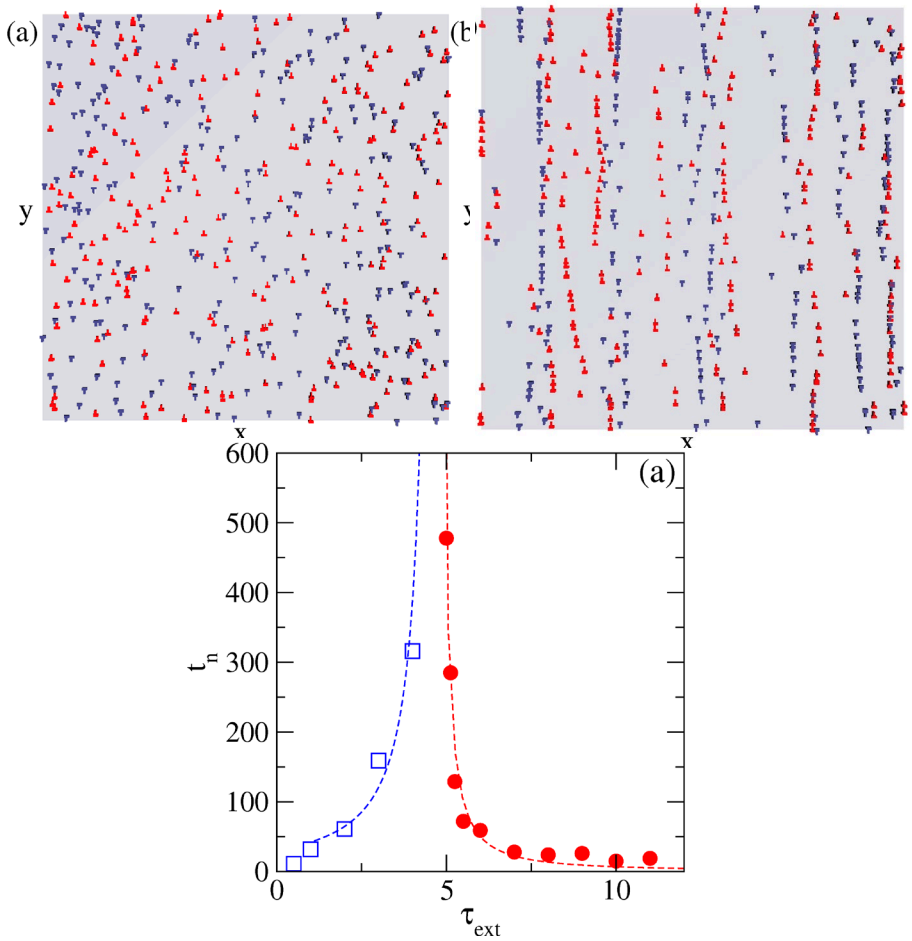
Transitions in the same class as clogging: Plasticity

Cyclically sheared amorphous materials



I. Regev et al, Nature Commun. 6, 8805 (2015)

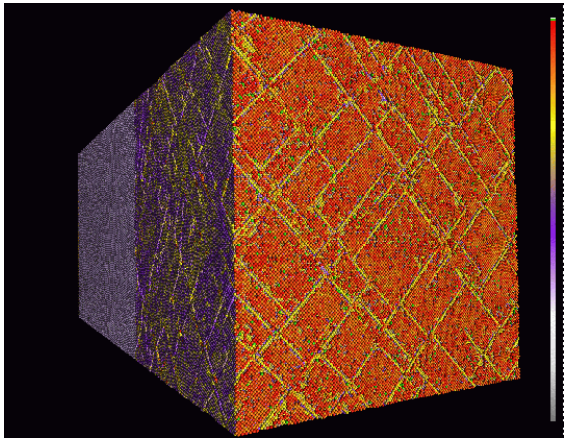
Dislocation motion under cyclic shear



Sci. Rep. 5, 8000 (2015)

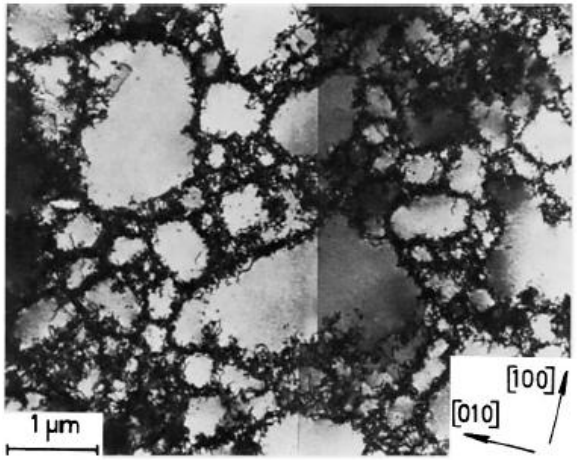
Disorder and the bridge between scales

Atomistic



BL Holian, PS Lomdahl,
Science 280, 2085 (1998)

Mesoscale



H Mughrabi et al,
Acta Metal. 31, 1367 (1983)

Macroscale

Summary

- **Identification of new categories of disorder**
- **Jammed states**
  - Similar to equilibrium phase transition
  - Length scale diverges as a power law
- **Hyperuniform states**
  - Nonuniform on short length scales, uniform on large length scales
  - Structure factor goes to zero as a power law
- **Clogged states**
  - Nonuniform on medium and long length scales
  - Time to form diverges as a power law
- **New tools for understanding materials response at long times or under extreme conditions**

Coauthors of presented work

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  - Paul Johnson (LANL)
  - Andras Libal (Babes-Bolyai University)
  - Danielle McDermott (Pacific University)
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For additional technical details, see http://cnls.lanl.gov/~olson/research.html